Chapter 1b: An age-structured assessment of pollock (*Theragra chalcogramma*) from the Bogoslof Island Region

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Executive Summary

In 1987 pollock catch peaked in the Bogoslof region (INPFC area 518) with over 370,000 tons reported. During the period from 1985 to 1991, a total of 932,996 t of pollock were caught in this region. NMFS subsequently closed this area to directed pollock fishing (1992-2005) due in part to agreements under the Convention on the Conservation and Management of the Pollock Resources in the Central Bering Sea. Under this convention, the Bogoslof spawning aggregations are linked to the abundance of pollock found in international waters of the Aleutian Basin. As part of the monitoring program for the Convention, sixteen annual Echo Integration Trawl (EIT) surveys of Bogoslof pollock abundance have been undertaken since 1988. This document presents an integrated analysis of these data through an age-structured assessment. Results from these analyses suggest that the survey data are very informative and that the current spawning stock size may be nearly 2-fold higher than the $B_{40\%}$ level (or about 77% of the $B_{100\%}$ level). Estimates of natural mortality from these data are somewhat higher than previously assumed values for pollock in this region (0.256 compared to 0.20). The extent to which this stock is vulnerable to fisheries in other regions (e.g., the EBS shelf and in Russian waters) is a key question. As with pollock observed in the US, Russian, and international zones, the 1978 year class dominated the Bogoslof population; its strength is more than 10 times the average year class strength. Favorable environmental conditions are thought to play a major role in the production of year-classes of this magnitude. This high level of natural variability should be considered in management recommendations, particularly in setting realistic target stock levels.

Summary of Major Changes

<u>Changes to the input data</u>
In the winter of 2005 an echo-integration trawl (EIT) survey was conducted and biomass and age composition estimates from this research were included in this assessment.

Fishery catch estimates were recompiled to the extent possible back to 1977.

Fishery age compositions for 1987 were compiled and included in this assessment.

Since the September meeting the average weights-at-age were computed using the EIT survey estimates. The values presented in the September draft were borrowed from the EBS fishery and were preliminary. The EIT estimates show a marked increase in mean weight-at-age over time that may be related to density dependent effects on growth.

<u>Changes in the assessment methodology</u>
This is the first time Bogosolof pollock have been compiled as a separate assessment chapter. Relative to past assessments used for this stock, this presents an age structured assessment suitable for management under Tier 3 of amendment 56 whereas previously it has been managed exclusively under Tier 5 (survey-

based approach) or some modification thereof. In 1999 a preliminary age-structured model was developed and presented but this was not used for ABC recommendations.

Changes in the assessment results

The age structured model estimates indicate that this stock is above the $B_{40\%}$ level and hence could qualify for Tier 3a recommendations under Amendment 56 of the FMP. This results in maximum permissible ABC recommendations of:

Year	ABC	OFL
2006	190,000 t	240,500 t
2007	244,000 t	306,100 t

The increase is due to the appearance of the strong 2000 year class into this region (but the strength in this region is highly uncertain). Given the current uncertainty about stock structure and our lack of understanding on where Bogoslof pollock pre-recruits reside, it seems prudent to continue to set the ABC at levels suitable for bycatch in other fisheries.

Response to SSC comments

In their December 1999 minutes, the SSC commented:

> "The SAFE contains an interesting [Bogoslof region] age-structured model for this stock using only data from the Bogoslof surveys. If we were willing to ignore the connection of Bogoslof pollock to the Aleutian Basin, then this model could provide a basis for determining ABC. However, we continue to believe that Bogoslof pollock are related to the Aleutian Basin stock, and therefore, ignoring data from the entire stock does not constitute use of best available information for this stock."

In the present assessment, the selected model configuration allows for the assumption that the echo-integration trawl (EIT) surveys are a relative index for the Bogoslof (Aleutian Basin) stock.

In their October 2005 minutes, the SSC requested model runs that include Aleutian Basin catches. This will be pursued next year. They also commented that total biomass may be inappropriate to report since the survey gear should be able to assess younger ages if present. Therefore, they recommend evaluating the use of exploitable biomass (the sum of selectivity times biomass over age) to better reflect biomass for the Tier 5 estimates of ABC and OFL. It should be noted that the selectivity by the survey is estimated to be nearly identical to that of the fishery. Therefore the use of survey biomass estimates for Tier 5 calculations should satisfy their concerns.

Introduction

Alaska pollock (*Theragra chalcogramma*) are broadly distributed throughout the North Pacific with largest concentrations found in the Eastern Bering Sea. The Bogoslof region is noted for having distinct spawning aggregations that appear to be independent spawning in adjacent regions.

The Bogoslof management district (INPFC area 518) was established in 1992 in response to fisheries and surveys conducted during the late 1980s, which consistently found a discrete aggregation of spawning pollock in this area during the winter. The degree to which this aggregation represents a unique, self-recruiting stock is unknown but the persistence of this aggregation suggests some spawning site fidelity that called for management. The Bogoslof region pollock has also been connected with the historical abundance of pollock found in the central Bering Sea (Donut Hole) due to concentrations of pollock successively moving toward this region prior to spawning (Smith 1981, Shuntov et al. 1993). Collectively, pollock found in the Donut Hole and in the Bogoslof region are considered a single stock, the Aleutian Basin stock. Currently, 60% of the Aleutian Basin pollock population is thought to spawn in the Bogoslof region. The actual distribution of Aleutian Basin pollock likely varies depending on environmental conditions and the age-structure of the stock.

The Bogoslof component of the Aleutian Basin stock is one of three management stocks of pollock recognized in the BSAI region. The other stocks include pollock found in the large area of the Eastern Bering Sea shelf region and those in the Aleutian Islands near-shore region (i.e., less than 1000m depth; Barbeaux et al. 2004). The Aleutian Islands, Eastern Bering Sea and Aleutian Basin stocks probably intermingle, but the exchange rate and magnitude are unknown. The degree to which Aleutian Basin stock contribute to subsequent recruitment to the Aleutian Basin stock also is unknown. From an early life-history perspective, the opportunities for survival of eggs and larvae from the Bogoslof region seem smaller than for other areas (e.g., north of Unimak Island on the shelf). There is a high degree of synchronicity among strong year-classes from these three areas, which suggests either that the spawning source contributing to recruitment is shared or that conditions favorable for survival are shared.

From a biological perspective, the degree to which these management units are reasonable definitions depends on the active exchange among these stocks. If they are biologically distinct and have different levels of productivity, then management should be adjusted accordingly. Bailey et al. (1999) present a thorough review of population structure of pollock throughout the north Pacific region. They note that adjacent stocks were not genetically distinct but that differentiation between samples collected on either side of the N. Pacific was evident. There are some characteristics that distinguish Bogoslof region pollock from other areas. Growth rates appear different (based on mean-lengths at age) and pollock sampled in the Bogoslof Island survey tend to be much older. For example, the average percentage of age 15 and older pollock observed from the Bogoslof EIT survey since 1988 is 18%, while for the same period in the EBS region (from model estimates), age 15 and older averages only 2% (by number for all fish older than age 7).

The information available for pollock in the Aleutian Basin and the Bogoslof Island area indicates that these fish may belong to the same "stock". The pollock found in winter surveys are generally older than age 4 and are considered distinct from eastern Bering Sea pollock. Although data on the age structure of Bogoslof pollock show that a majority of pollock originated from year classes that were also strong on the shelf, 1972, 1978, 1982, 1984, 1989, 1992, 1996, and 2000, there has been some indication that there are strong year classes appearing on the shelf that have not been as strong (in a relative sense) in the Bogoslof region (Ianelli et al., 2004). Strong year classes of pollock in Bogoslof may be functionally related to abundance on the shelf.

Fishery

Prior to 1977, few pollock were caught in the Donut Hole or Bogoslof region (Low and Akada 1978). Japanese scientists first reported significant quantities of pollock in the Aleutian Basin in the mid-to-late 1970's, but large scale fisheries did not occur until the mid-1980's in the Donut Hole. By 1987 significant components of these catches were attributed to the Bogoslof Island region (Table 1b.1), although the actual locations are poorly documented. The Bogoslof fishery primarily targeted winter spawning-aggregations. Since 1992, the Bogoslof management district has been closed to directed pollock fishing. During summer months, pollock distribution is diffuse and no directed pollock fishery has occurred.

In 1991, the only year with extensive observer data, the fishery timing coincided with the open seasons for the EBS and Aleutian Islands pollock fisheries (recall that the Bogoslof management district was not yet established). However, after March 23, 1991 the EBS region was closed to fishing and some effort was re-directed to the Aleutian Islands region but adjacent to the Bogoslof district (Fig. 1b.1). In subsequent years, seasons for the Aleutian Islands pollock fishery were managed separately. Bycatch and discard levels were relatively low from these areas when there was a directed fishery (e.g., 1991). Pollock retention levels are variable and have increased as bycatch from other fisheries in this area has increased (Table 1b.2).

Data

Fishery

We estimate the catch-at-age composition using the methods described by Kimura (1989) and modified by Dorn (1992). Age-length keys were constructed from length-stratified age data by stratum and sex, then applied to randomly sampled length frequency data. Length sample sizes are low except during 1985-1991 (Fig. 1b.2; Table 1b.3). The resultant catch-at-age compositions show the strong 1978 year-class through the population as it grew over time. Indeed, in the one year where sufficient age-determination samples were collected and processed (1987) the number of 9-year olds dominated the catch (Table 1b.4).

Echo-integration trawl (EIT) surveys

The National Marine Fisheries Service has conducted echo-integration-trawl (EIT) surveys for Aleutian Basin pollock spawning in the Bogoslof Island area annually since 1988, except that the survey was not conducted in 1990 or 2004, and in 1999, the survey was conducted by the Fisheries Agency of Japan. Survey reports have appeared in various publications (Table 1b.5). The timing of the survey has varied in different years but has generally occurred in late February and/or early March (Fig. 1b.3). Sample sizes for lengths, weights, and ages have been quite high (Table 1b.6).

Survey abundance declined between 1988 and 1994, was stable and variable, then dropped again to the level it has maintained since 2000 (Fig 1b.4; Table 1b.7). The 1989 year class recruited to the Bogoslof Island area and was partly responsible for the 1995 increase (Fig. 1b.5; Table 1b.8), but the abundance of all ages increased between 1994 and 1995. The decrease between 1995 and 1996 was followed by a continued decline in 1997, suggesting that the 1995 estimate may be high, or that conditions in that year affected the apparent abundance of pollock. The 1996 year class has appeared to some degree in the 2005 survey, while the 1999 and 2000 year classes appear to be strong.

Analytic approach

Model structure

The age-structured analysis was conducted using the AMAK model (as is used for the Aleutian Islands pollock and BSAI Atka mackerel stocks). The technical aspects of this model are presented in these reports (Barbeaux et al. 2004, Lowe et al. 2004). Briefly, the model structure is developed following Fournier and Archibald's (1982) methods, with a number of similarities to Methot's extension (1990). The model is implemented using automatic differentiation software developed as a set of libraries under the C++ language (AD Model Builder). The catch-equation was formulated assuming fishing mortality occurred instantaneously at the mid-point of the year. The first age of recruitment was set at age 5 since younger fish are rarely found in the survey or the fishery. Fish of age 15 and older were pooled into a single age group (labeled 15+).

Parameters estimated independently

Natural Mortality and maturity at age
We initially assumed M = 0.2 (Wespestad and Terry 1984), but relaxed this assumption for some models, including estimation of natural mortality. Maturity at age was assumed to be (Ianelli et al. 2004):

Age	5	6	7	8	9	10	11	12	13	14	15+
M	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Prop. Mature	0.842	0.902	0.948	0.964	0.970	1.000	1.000	1.000	1.000	1.000	1.000

Length and Weight at Age
EIT survey estimates of mean body-weight at age by year, sexes combined (Table 1b.9) were used to convert model estimates of catch-at-age (in numbers) to model estimates of total annual harvests (by weight). The mean body weight values were computed by dividing the EIT estimated biomass-at-age by the estimated population numbers-at-age. The 2004 data were computed as averages from the 2005 and 2003 average weights at age.

EIT survey catchability
Initially we assumed that survey catchability equaled 1.0, i.e., that the survey indexes absolute abundance, relaxing this assumption for some models. For catchability less than one, one interpretation is that only a fraction of the stock is available during the period of EIT survey operations (i.e., that there are other components to the "Aleutian Basin" stock.

Parameters estimated conditionally

For the Model 4 presented here, 61 parameters were estimated. These include vectors describing recruitment variability in the first year (as ages 5-15 in 1977) and the recruitment deviations (at age 5) from 1977-2005. Additionally, projected recruitment variability was also estimated (using the estimated variance of past recruitments) for 10 years (2006-2015). The two-parameter stock-recruitment curve is included in addition to a term that allows the average recruitment before 1977 (that comprises the initial age composition in that year) to have a mean value different from subsequent years. With the value for recruitment variability about the curve, the total for recruitment-related parameters is 53.

Fishing mortality is parameterized to be the same for all ages greater than age 6 since this fishery comprises mainly spawning aggregations and only one year of fishery age composition data is available. As with the survey data, the ages 5 and 6 occur less commonly in this area and hence the vulnerability for these ages is estimated (resulting in 6 parameters, 3 each for the survey and fishery). Finally, for Model 4, values for natural mortality rate and survey catchability are estimated as free parameters.

The likelihood components can thus be partitioned into the following groups:

- Log-normal indices of abundance for the EIT survey (values of σ=0.2 were assumed)
- Fishery and survey proportions-at-age estimates (multinomial with effective sample sizes presented in Table 1b.10).

- Slight selectivity constraints on ages 5 and 6 for both the survey and fishery, constant value for ages 7 and older
- Stock-recruitment: non-informative prior distribution assumed to fit the stochastic stock-recruitment relationship within the integrated model

Model evaluation

A list of the models presented includes:

Model 1 Fixed steepness, natural mortality, survey catchability; standard survey area

Model 2 As Model 1 but estimate stock-recruitment relationship (Ricker)

Model 3 As Model 2 but estimate natural mortality (*M*)

Model 4 As Model 3 but estimate survey catchability

Model 5 As Model 1 but fit a Beverton-Holt stock-recruitment relationship (Beverton and Holt, 1957)

Model 6 As Model 4 but fit a Beverton-Holt stock-recruitment relationship

Model 7 As Model 4 but expanded survey data (include areas adjacent to INPFC area 518)

These models can be summarized as follows:

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
Stock-recruitment	Ricker	Ricker	Ricker	Ricker	Beverton Holt	Beverton-Holt	Ricker
Steepness	Fixed 0.7	Estimated	Estimated	Estimated	Fixed 0.7	Estimated	Estimated
M	Fixed 0.2	Fixed 0.2	Estimated	Estimated	Fixed 0.2	Estimated	Estimated
Survey q	Fixed 1.0	Fixed 1.0	Fixed 1.0	Estimated	Fixed 1.0	Estimated	Estimated
Survey area	Standard	Standard	Standard	Standard	Standard	Standard	Expanded

Results

The main model results are summarized in Table 1b.11. The models where natural mortality was estimated tended to have higher peak biomass levels than those where it was assumed equal to 0.2 (Fig. 1b.6). From a biological standpoint, the tendency towards higher natural mortality estimates suggests that additional losses occur either due to movement out of the region or from additional unaccounted mortality.

For illustrative purposes, Model 4 was adopted for the remaining presentation since it had the best fit to the data and fewer assumptions. Model 3 may be a slightly more parsimonious model configuration (requiring one fewer parameter at little cost to the total -ln(Likelihood) value). However, the additional assumption results in the perception of greater model certainty—the coefficient of variation on 2006 biomass level is lower for Model 3.

The estimated Model 4 selectivity patterns are similar for both the survey and fishery (Fig. 1b.7), which is unsurprising because the timing and location of the fishery and the EIT survey largely overlap.

The overall trend in abundance relative to the EIT survey time series shows a series of positive residuals during the late 1980s and early 1990s (Fig. 1b.8). The Model 4 fit to the EIT survey age composition data shows some variability in the estimates of above-average year-classes (Fig. 1b.9). The proportions-at-age observed in the survey are generally consistent with what appeared in the fishery from 1987 (Fig. 1b.10).

Estimated numbers-at-age for Model 4 are presented in Table 1b.12 and estimated catch-at-age presented in Table 1b.13. Estimated summary biomass (age 5+), female spawning biomass, age 5 recruitment, and full-selection fishing mortality for Model 4 is given in Table 1b.14. A comparison of these biomass levels, together with the predicted and observed survey estimates, is given in Figure 1b.11.

Abundance and exploitation trends

Biomass levels increased from 1979 to the mid-1980's (Table 1b.14) primarily due to the recruitment of the strong 1978 year class (Table 1b.12). The abundance and exploitation pattern estimated from Model 4 shows that the fishing mortality rate was high (in excess of 0.3) during the late 1980s when the largest removals reported from this region occurred (Fig. 1b.12).

Recruitment

As with pollock observed in the US, Russian, and international zones, the 1978 year class dominated the Bogoslof population as a major event. For the Bogoslof region the magnitude of this year-class is more than 10 times the average. Favorable environmental conditions are thought to play a major role in the production of year-classes of this magnitude. For the Bogoslof region, density dependent processes affecting subsequent recruitment likely occur outside of this region since the area is relatively small and the winter spawning aggregations appear to disperse or move to other regions. Since this and issues related to stock structure remain uncertain, harvest recommendations based on a fitted stock-recruitment relationships were avoided (Fig. 1b.13).

Projections and harvest alternatives

Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines “overfishing level” (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. Reference points related to maximum sustainable yield (MSY) were estimated but considered inappropriate for an initial presentation. Therefore, reference points for pollock in the Bogoslof region are based solely on Tier 3 of Amendment 56. The reference point estimates from Model 4 results that were computed based on recruitment from post-1976 spawning events (which includes the 1978 year-class) were:

$B_{100\%}$ = 351,100 thousand t female spawning biomass

$B_{40\%}$ = 140,400 thousand t female spawning biomass

$B_{35\%}$ = 122,900 thousand t female spawning biomass.

Standard Harvest Scenarios and Projection Methodology

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3, of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2005 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2006 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2005. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2006, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2006 recommended in the assessment to the *max* F_{ABC} for 2006. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 2001-2005 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2005 or 2) above ½ of its MSY level in 2005 and above its MSY level in 2016 under this scenario, then the stock is not overfished.)

Scenario 7: In 2006 and 2007, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2017 under this scenario, then the stock is not approaching an overfished condition.)

Projections and status determination

For the purposes of these projections, we present results based on selecting the $F_{40\%}$ harvest rate as the max F_{ABC} value and use $F_{35\%}$ as a proxy for F_{msy}. Scenarios 1 through 7 were projected 14 years from 2005 (Table 1b.15). Under Scenario 1, the expected spawning biomass is projected to decrease and then stabilize to above $B_{40\%}$ by the year 2010 (Fig. 1b.14). Under this scenario, the yields are expected to vary between 50 – 200 thousand tons. If the highly conservative catch levels (estimated from the last 5 years) are to continue, then the stock is projected to remain stable (Fig. 1b.15).

Any stock that is below its minimum stock size threshold (MSST) is defined to be overfished. Any stock that is expected to fall below its MSST in the next two years is defined to be approaching an overfished condition. Harvest scenarios 6 and 7 are used in these determinations as follows:

Is the stock overfished? This depends on the stock's estimated spawning biomass in 2006:

a) If spawning biomass for 2006 is estimated to be below ½ $B_{35\%}$ the stock is below its MSST.
b) If spawning biomass for 2006 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c) If spawning biomass for 2006 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest scenario 6 (Table 15). If the mean spawning biomass for 2017 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario 7:

a) If the mean spawning biomass for 2008 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2008 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2008 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2017. If the mean spawning biomass for 2017 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

For scenarios 6 and 7, we conclude that pollock is not below MSST for the year 2006, nor is it expected to be approaching an overfished condition based on Scenario 7.

Specification of OFL and Maximum Permissible ABC

In this section standard age-structured results are presented for a Tier 3a (amendment 56) ABC calculation. Past methods and a recommendation are presented in the subsequent section. For Model 4, the year 2005 female spawning biomass is estimated to be **253,900** thousand tons (at the time of spawning, assuming the stock is fished at $F_{40\%}$). This is well above the $B_{40\%}$ value of **140,400** (and the $B_{35\%}$ value of 122,900). The maximum-permissible ABC and OFL levels are thus **190,000** t and **240,500** t, respectively. The values for 2007 (assuming 2006 catches are similar to 2005) gives ABC and OFL of **244,000** t and **306,100** t, respectively

ABC Recommendation

Since 1999 the North Pacific Fishery Management Council (NPFMC) has generally been presented with a number of alternative methods for computing ABC values for the Bogoslof region. These have included:

1. Using a biomass-adjusted harvest rate rule (with 2,000,000 ton estimate as a target stock size) with an estimate of a F_{ABC} based on growth, natural mortality, and maturation rate.
2. Using a harvest rate as a simple fraction of natural mortality rate (e.g., F_{ABC} =0.75M).
3. An approach using the age-structured model presented in this document.

Historically, the NPFMC Science and Statistical Committee (SSC) considered the third approach using the age-structured model to be inappropriate since it was thought this region only covered part of the stock. While this may still be the case, the analysis carried out here is intended to provide some contrast and provides a more complete evaluation of the data from this region. Also, freely estimating survey catchability accounts to some degree for pollock lying outside of the survey area.

The approach 1) and 2) above are provided below for comparison (along with alternative assumptions about F_{ABC} level for 1). Using method 1) above and given the survey estimate of exploitable biomass of 0.253 million t and M = 0.2 and considering of a target stock size of 2 million tons, the F_{ABC} level is computed as:

$$F_{abc} \le F_{40\%} \bullet \left(\frac{B_{2005}}{B_{\text{Target}}} - 0.05 \right) \Big/ \left(1 - 0.05\right) \ .$$

Assuming that $F_{40\%}$ = 0.27 (as in past assessments), this gives a fishing mortality rate of 0.0217 that translates to an exploitation rate of 0.0215. This value multiplied by 253,000 t, gives a **2006 ABC of**

5,501 t for the Bogoslof region. The value assumed for $F_{40\%}$ that is critical for this calculation was based on uncertain assumptions about selectivity, natural mortality, growth, and maturation. Some of these assumptions were reevaluated here using a simple knife-edged selectivity at age 4 and age 5. Female pollock were specified to be 50% mature by age 5 and immature for younger pollock and 100% mature for older pollock with a natural morality of 0.3. This results in an $F_{40\%}$ level of 0.22 for the age-4 knife edge assumption and $F_{40\%}$ = 0.33 for the age-5 knife-edge assumption. These two scenarios provide ABCs for 2006 that would be 4,482 t or 6,723 t for the age-4 and age-5 knife edge assumptions, respectively. Clearly, these rules are sensitive to assumptions about expected selectivity, assumed growth, natural mortality, and maturation rates.

The approach for computing ABC levels under 2) above (a Tier 5 computation) simply uses the most recent survey biomass estimate applied to an adjusted natural mortality. Given a value of $M=0.3$ then the ABC level would be (2005 survey biomass $\times M \times$ 0.75) of **56,925 t** at a biomass of 253,000 t. With $M = 0.2$, the ABC would be 37,950 t.

The age-structured model presented here provides a number of new results. First, the value estimated for $F_{40\%}$ (assuming the selectivity and natural mortality are as estimated and given the assumed proportion mature at age) is higher than that assumed above (although the exploitation rate—catch over total biomass—is about 30%). Also, the reference points are quite different. Assuming that the 2,000,000 t "target" represents ~1 million t of female spawning biomass, then the target of 133,000 t of female spawning biomass presented above is substantially smaller. The current Bogoslof stock size is about nearly two times the target level ($B_{40\%}$) and about 77% of the "unfished" level (which given observed recruitment at age 5 to this region is 351,100 t of female spawning biomass). The maximum-permissible ABC using the age-structured model gives a 2006 ABC level of 190,000 t.

Forward simulations using Model 4 results (and fishing using the maximum permissible ABC) show that the 90 percentile range of female SSB is between about 75,000 t and 250,000 t (Fig. 1b.14). Under a no-fishing scenario, this range increases to between 200,000 and 500,000 t (Fig. 1b.16). This reflects the main characteristic that seems to prevail for basin pollock: they are highly susceptible to year-class variability.

In summary, there is a broad range of ABC levels that have been calculated under the NPFMC guidelines. The third approach (age-structured model) results in the highest ABC levels. The age-structured model, while currently under review by the SSC, could be argued to represent an alternative method to set ABCs and subsequent TACs. Given the current uncertainty about stock structure and our lack of understanding on where Bogoslof pollock pre-recruits reside, it seems prudent to set the ABC at levels suitable for bycatch in other fisheries. This would be closest to the recent 5-year average fishing mortality level (Scenario 4) which indicates an ABC level of 471 t. A summary of the results is given in Table 1b.16.

Ecosystem considerations

In general, a number of key issues for ecosystem conservation and management can be highlighted. These include:

- Preventing overfishing;
- Avoiding habitat degradation;
- Minimizing incidental bycatch (via multi-species analyses of technical interactions);
- Controlling the level of discards; and
- Considering multi-species trophic interactions relative to harvest policies.

For the case of pollock, the NPFMC and NMFS continue to manage the fishery on the basis of these issues in addition to the single-species harvest approach. The prevention of overfishing is clearly set out as a main guideline for management. Habitat degradation has been minimized in the pollock fishery by converting the industry to pelagic-gear only. Bycatch in the pollock fleet is closely monitored by the

NMFS observer program, and individual species caught incidentally are managed on that basis. Discarding rates have been greatly reduced in this fishery and multi-species interactions is an ongoing research project within NMFS with extensive food-habit studies and simulation analyses to evaluate a number of "what if" scenarios with multi-species interactions.

As reported in Loughlin and Miller (1989) pups of Northern fur seals, *Callorhinus ursinus*, were first observed on Bogoslof Island in 1980. By 1988 the population had grown at a rate of 57%/yr to over 400 individuals, including 80+ pups, 159 adult females, 22 territorial males, and 188 subadult males. They noted that rookery is in the same location where solitary male fur seals were seen in 1976 and 1979 and is adjacent to a large northern sea lion rookery. On July 22, 2005 NMFS survey efforts counted 1,123 adult males, a substantial increase over this time period (L. Fritz, AFSC, pers. comm.). This suggests that conditions in the ecosystem have changed and appear to favor Northern fur seals. The extent that this is due to environmental conditions is unknown. However, pollock abundance may play only a small role since during peak abundance levels, the Northern fur seal abundance was at very low levels. Also, pollock are most concentrated in this region during winter months when Northern fur seals have migrated to more southern areas.

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Tables

Table 1b.1 Catch in tons from the Donut Hole and the Bogoslof Island area, 1977-2005.

Year	Donut Hole	Bogoslof I.
1977		11,500
1978		9,600
1979		16,100
1980		13,100
1981		22,600
1982		14,700
1983		21,500
1984	181,200	22,900
1985	363,400	13,700
1986	1,039,800	34,600
1987	1,326,300	377,436
1988	1,395,900	87,813
1989	1,447,600	36,073
1990	917,400	151,672
1991	293,400	316,038
1992	10,000	241
1993	1,957	886
1994		556
1995		334
1996		499
1997		163
1998		136
1999		29
2000		29
2001		258
2002		1,042
2003		24
2004		100
2005		100

Table 1b.2. Estimated retained, discarded, and percent discarded of total pollock catch (t) from the Bogoslof region. Source: NMFS Regional office Blend database and catch accounting system.

Year	Discard	Retained	Total	Percent Discard
1991	20,327	295,711	316,038	6%
1992	240	1	241	100%
1993	308	578	886	35%
1994	11	545	556	2%
1995	267	66	334	80%
1996	7	492	499	1%
1997	13	150	163	8%
1998	3	133	136	2%
1999	11	18	29	39%
2000	20	10	29	67%
2001	28	231	258	11%
2002	12	1,031	1,042	1%
2003	19	5	24	79%
2004	0.01	0	0.01	

Table 1b.3. Numbers of fishery samples used for lengths (measured), otoliths collected ("Collected") and number of age determinations (Aged) made for 1978-2004. These represent pollock as sampled by the NMFS observer program. Note that all otolith collections included a body weight measurement.

Lengths

Year	Male	Female	Unsexed	Total
1978	25	47	2	74
1979	80	65		145
1980	42	49		91
1981	408	557		965
1982	151	267		418
1983	231	239		470
1984	239	513		752
1985	470	318		788
1986	7,593	10,467		18,060
1987	77,860	98,333	10	176,203
1988	52,848	40767	3	93,618
1989	391	322		713
1990				
1991	73,550	67257	365	141,172
1992			12	12
1993				
1994				
1995	101	156		257
1996	511	486		997
1997	146	115		261
1998	93	78		171
1999	30	36	20	86
2000	41	60		101
2001	4	16		20
2002	8	12		20
2003				
2004	11	11		22
Total	214,833	220,171	412	435,416

Otoliths

Year	Aged	Unaged	Total collected
1978	10		10
1981	18		18
1982	1		1
1983	21		21
1987	683		683
1991	188	1,637	1,825
1996		10	10
1997	17	2	19
1998	5	5	10
	943	1,654	2,597

Table 1b.4. Bogoslof Region walleye pollock catch at age (in thousands) estimates based on observer data, 1987.

Year	6	7	8	9	10	11	12	13	14	15+	Total
1987	18,727	28,386	65,466	228,550	60,057	44,416	34,412	23,612	12,416	10,454	526,495

Table 1b.5. Publication lists documenting each of the Bogoslof surveys conducted by NMFS.

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Table 1b.6. Number of hauls and sample sizes for age and length taken during the Bogoslof pollock EIT surveys, 1988-2005 based on cruise reports. The 1999 survey effort from the Japanese vessel is not included.

Year	**Number of hauls**	**Number of pollock sampled for length**	**Number of pollock sampled for ages**
1988	20	5,708	888
1989	11	3,238	643
1991	16	3,639	818
1992	13	3,312	1,004
1993	13	3,173	1,056
1994	13	3,162	890
1995	19	6,003	1,213
1996	17	5,161	1,271
1997	16	5,066	1,121
1998	14	4,013	1,182
2000	11	2,782	621
2001	14	3,993	815
2002	11	3,276	988
2003	5	1,804	346
2005	19	4,095	1,000

Table 1b.7. Abundance at age (millions) of pollock as surveyed in the Bogoslof region (standard area), 1988-2005. Note that in 1999 the Fishery Agency of Japan conducted the survey.

Age	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
5	27.9	15.2	—	11.7	26.6	16.7	86.2	74.9	5.6	3.7	11.4	5.4	5.7	14	2.7	6.0	—	81.0
6	326.7	58.4	—	46.3	54.0	43.8	25.8	278.3	96.1	15.8	60.7	28.7	4.4	12	40.7	6.5	—	30.7
7	246.8	362.8	—	213.1	96.8	46.4	37.7	104.7	187.3	55.5	34.0	77.0	14.1	10	11.3	24.7	—	12.5
8	163.7	147.0	—	93.5	74.2	48.3	36.5	67.7	85.3	87.5	69.5	34.3	30.3	10	7.6	10.6	—	11.3
9	350.1	194.3	—	160.0	71.3	42.2	36.1	80.1	40.2	38.2	77.0	49.7	15.7	14	6.4	4.1	—	21.8
10	1200.9	90.7	—	44.1	54.8	28.3	16.9	53.4	37.0	27.7	32.1	74.8	28.4	12	6.6	4.5	—	7.1
11	287.8	1105.4	—	92.0	56.6	51.1	26.8	54.1	24.1	16.2	24.5	29.2	44.9	18	7.9	4.0	—	3.4
12	287.3	222.3	—	59.7	33.1	25.1	23.1	19.1	24.3	15.8	20.7	26.9	20.8	31	14.3	10.1	—	4.9
13	201.9	223.1	—	372.9	34.4	26.8	12.8	58.8	12.4	12.6	18.6	24.6	16.2	13	29.8	7.9	—	4.3
14	89.2	81.8	—	119.1	142.1	42.1	8.5	31.6	36.4	7.2	18.5	15.6	11.1	7	8.8	25.5	—	5.2
15+	53.9	180.4	—	200.7	328.6	208.5	146.1	249.0	117.1	55.7	67.4	47.5	36.6	27	29.4	21.3	—	36.2
Total	3,290	2,862	—	1,614	1,301	788	603	1,321	783	392	435	416	229	170	181	134	—	225

Table 1b.8. Biomass (tons) of pollock as surveyed in the Bogoslof region, 1988-2005. Note that in 1999 the Fishery Agency of Japan conducted the survey. Estimates labeled "Expanded area" represent the inclusion of pollock found to continue beyond the standard-area boundaries (see Table 1b.5 for list of references documenting these surveys).

Year	**Standard area**	**Expanded area**
1988	2,396,000	2,396,000
1989	2,084,000	2,126,000
1990	NO SURVEY	
1991	1,283,000	1,289,000
1992	888,000	940,000
1993	631,000	635,000
1994	490,000	490,000
1995	1,020,000	1,104,000
1996	582,000	682,000
1997	342,000	392,000
1998	432,000	492,000
1999	393,000	475,000
2000	270,000	301,000
2001	208,000	232,000
2002	227,000	227,000
2003	198,000	198,000
2004	NO SURVEY	
2005	253,000	253,000

Table 1b.9. Annual average pollock weights-at-age (kg) used for the Bogoslof region assessment model. These values are used in the model for computing the predicted fishery catch (in weight) and for computing biomass levels for Bogoslof pollock. The italicized values used for 1977-1990 are the average from 1991-1995 whereas the values in 1999 and 2004 are averages from the year before and the year after.

	5	6	7	8	9	10	11	12	13	14	15+
1977-1990	*0.677*	*0.744*	*0.827*	*0.942*	*1.043*	*1.105*	*1.151*	*1.148*	*1.170*	*1.155*	*1.113*
1991	0.520	0.538	0.671	0.798	0.931	0.986	1.022	0.993	1.012	0.976	0.969
1992	0.806	0.705	0.693	0.801	0.944	1.039	1.086	1.096	1.083	1.057	1.082
1993	0.716	0.893	0.927	0.971	1.042	1.084	1.161	1.078	1.118	1.116	1.122
1994	0.695	0.835	1.054	1.073	1.096	1.214	1.178	1.192	1.327	1.282	1.161
1995	0.650	0.749	0.790	1.068	1.201	1.203	1.306	1.383	1.312	1.343	1.229
1996	0.659	0.719	0.883	0.887	1.138	1.227	1.294	1.370	1.370	1.344	1.221
1997	0.560	0.673	0.894	1.081	1.152	1.367	1.415	1.420	1.434	1.482	1.373
1998	0.593	0.621	0.872	1.060	1.226	1.261	1.456	1.407	1.438	1.422	1.332
1999	*0.652*	*0.642*	*0.863*	*1.031*	*1.182*	*1.333*	*1.434*	*1.472*	*1.490*	*1.502*	*1.417*
2000	0.710	0.662	0.854	1.002	1.137	1.404	1.411	1.536	1.542	1.582	1.501
2001	0.819	0.900	1.003	1.180	1.287	1.358	1.502	1.593	1.583	1.565	1.513
2002	0.734	0.837	0.893	1.179	1.254	1.385	1.563	1.599	1.609	1.663	1.508
2003	0.897	0.952	1.057	1.150	1.469	1.847	1.805	1.815	1.815	1.842	1.752
2004	*0.771*	*0.886*	*1.069*	*1.218*	*1.399*	*1.635*	*1.780*	*1.831*	*1.824*	*1.864*	*1.833*
2005	0.645	0.819	1.081	1.285	1.328	1.422	1.755	1.846	1.832	1.885	1.914

Table 1b.10. Pollock sample sizes assumed for the age-composition data likelihoods from the fishery, and EIT surveys, 1987-2005.

Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Fishery	200																		
EIT Survey		50	50		50	50	50	50	50	50	50	50	50	50	50	50	50		50

Table 1b.11. Results comparing fits Models 1-7. See text for additional model descriptions.

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
Likelihood components							
Fishery age composition	4.02	4.47	2.63	2.62	3.77	2.30	2.62
Survey index	39.90	39.67	21.53	21.59	39.36	21.59	22.99
Survey age composition	34.52	35.59	32.97	33.08	35.35	32.85	32.89
Fishery selectivity smoothness	1.61	1.53	1.58	1.62	1.50	1.60	1.64
Survey selectivity smoothness	0.23	0.21	0.24	0.24	0.22	0.25	0.25
Recruitment likelihood	45.37	36.18	49.74	48.42	39.13	50.37	48.21
Survey q prior	0.00	0.00	0.00	0.55	0.00	0.76	0.63
Other priors	0.19	0.09	0.16	0.16	0.05	0.10	0.16
Total -ln likelihood	125.85	117.74	108.86	108.29	119.37	109.83	109.39
Number of parameters	58	59	60	61	59	61	61
Key parameters							
Survey q	1.000	1.000	1.000	0.895	1.000	0.876	0.888
Natural Mortality	0.200	0.200	0.253	0.256	0.200	0.256	0.258
Steepness	0.700	0.394	0.374	0.375	0.808	0.808	0.372
σ_R	0.936	0.720	0.811	0.805	0.756	0.838	0.805
Estimates							
2006 Biomass	758,000	575,000	566,000	628,000	598,000	699,000	659,000
CV 2006 Biomass	12%	14%	15%	19%	15%	24%	18%
2006 F40 Catch	152,000	135,000	164,000	184,000	137,000	195,000	196,000
Exploitation rate at $F_{40\%}$	20%	23%	29%	29%	23%	28%	30%
$F_{40\%}$	0.309	0.307	0.453	0.464	0.307	0.463	0.472
$F_{35\%}$	0.403	0.400	0.608	0.624	0.398	0.623	0.636

Table 1b.12. Estimates of numbers at age for the Bogoslof region pollock stock under Model 4 (thousands).

Year	5	6	7	8	9	10	11	12	13	14	15+
1977	210,509	166,649	136,916	111,271	89,488	70,783	53,928	41,031	31,253	23,857	107,899
1978	348,264	162,496	128,023	104,298	84,763	68,169	53,920	41,080	31,256	23,808	100,368
1979	818,896	268,962	124,982	97,763	79,646	64,728	52,057	41,175	31,370	23,868	94,825
1980	957,611	631,460	206,088	94,702	74,078	60,350	49,046	39,445	31,200	23,770	89,937
1981	1,177,060	739,493	485,579	157,309	72,287	56,545	46,066	37,438	30,109	23,815	86,794
1982	925,577	908,176	567,448	369,036	119,554	54,938	42,974	35,010	28,452	22,882	84,062
1983	3,018,030	715,416	699,960	435,163	283,005	91,683	42,131	32,955	26,848	21,819	82,013
1984	565,109	2,332,270	551,112	536,222	333,368	216,803	70,236	32,275	25,246	20,568	79,544
1985	290,367	436,817	1,797,770	422,739	411,318	255,715	166,303	53,876	24,757	19,366	76,792
1986	227,352	224,659	337,492	1,385,560	325,809	317,007	197,082	128,171	41,523	19,081	74,110
1987	353,096	175,603	172,844	257,875	1,058,700	248,948	242,223	150,589	97,935	31,727	71,206
1988	165,229	264,356	124,873	111,581	166,473	683,451	160,711	156,369	97,214	63,223	66,449
1989	190,489	126,629	199,488	91,668	81,911	122,206	501,715	117,976	114,789	71,364	95,191
1990	131,910	146,782	96,854	150,603	69,205	61,838	92,259	378,768	89,066	86,660	125,740
1991	109,491	99,615	106,722	65,673	102,117	46,925	41,930	62,557	256,825	60,392	144,018
1992	105,410	78,920	64,008	54,008	33,234	51,678	23,747	21,219	31,658	129,970	103,444
1993	120,519	81,628	61,106	49,549	41,808	25,727	40,004	18,383	16,426	24,506	180,687
1994	279,757	93,308	63,169	47,251	38,314	32,329	19,894	30,933	14,215	12,701	158,668
1995	134,059	216,610	72,222	48,866	36,552	29,639	25,009	15,389	23,929	10,996	132,568
1996	67,778	103,810	167,703	55,898	37,821	28,291	22,940	19,356	11,911	18,521	111,114
1997	78,913	52,482	80,359	129,758	43,250	29,264	21,889	17,750	14,976	9,216	100,303
1998	46,323	61,111	40,638	62,214	100,459	33,484	22,656	16,947	13,742	11,595	84,790
1999	35,328	35,873	47,321	31,463	48,167	77,777	25,924	17,541	13,121	10,639	74,623
2000	49,189	27,360	27,781	36,645	24,365	37,301	60,231	20,076	13,584	10,161	66,027
2001	104,015	38,094	21,188	21,513	28,378	18,868	28,885	46,642	15,547	10,519	58,999
2002	49,570	80,542	29,490	16,395	16,647	21,959	14,600	22,352	36,092	12,030	53,793
2003	61,970	38,362	62,264	22,756	12,651	12,845	16,944	11,266	17,247	27,850	50,791
2004	114,204	47,990	29,704	48,203	17,617	9,794	9,944	13,118	8,722	13,352	60,881
2005	429,508	88,440	37,159	22,996	37,317	13,638	7,582	7,699	10,155	6,752	57,468
Median	165,229	126,629	106,722	91,668	72,287	54,938	42,131	32,955	26,848	21,819	84,790
Average	385,018	291,169	225,526	173,758	133,390	98,023	74,235	56,117	41,351	29,138	92,176

Table 1b.13. Estimated catch numbers-at-age of Bogoslof region pollock for Model 4 (thousands).

	5	6	7	8	9	10	11	12	13	14	15+
1977	695	1,352	2,261	1,837	1,478	1,169	890	677	516	394	1,782
1978	980	1,123	1,801	1,467	1,192	959	758	578	440	335	1,412
1979	3,574	2,885	2,728	2,134	1,738	1,413	1,136	899	685	521	2,069
1980	2,775	4,497	2,986	1,372	1,073	875	711	572	452	344	1,303
1981	4,436	6,849	9,151	2,965	1,362	1,066	868	706	567	449	1,636
1982	1,820	4,388	5,579	3,628	1,175	540	423	344	280	225	827
1983	6,565	3,824	7,614	4,734	3,078	997	458	358	292	237	892
1984	1,083	10,986	5,282	5,140	3,195	2,078	673	309	242	197	762
1985	282	1,041	8,717	2,050	1,994	1,240	806	261	120	94	372
1986	612	1,487	4,545	18,661	4,388	4,269	2,654	1,726	559	257	998
1987	12,805	15,651	31,346	46,767	192,000	45,148	43,928	27,310	17,761	5,754	12,914
1988	1,767	6,946	6,677	5,966	8,901	36,543	8,593	8,361	5,198	3,380	3,553
1989	971	1,587	5,087	2,337	2,089	3,116	12,793	3,008	2,927	1,820	2,427
1990	3,497	9,563	12,839	19,964	9,174	8,197	12,230	50,211	11,807	11,488	16,669
1991	9,236	20,650	45,017	27,702	43,075	19,794	17,687	26,388	108,333	25,474	60,749
1992	10	18	29	24	15	23	11	10	14	59	47
1993	37	62	94	77	65	40	62	28	25	38	279
1994	63	52	72	54	43	37	23	35	16	14	180
1995	17	67	45	31	23	19	16	10	15	7	83
1996	13	47	156	52	35	26	21	18	11	17	103
1997	5	9	27	43	14	10	7	6	5	3	33
1998	3	9	12	19	30	10	7	5	4	3	26
1999	1	1	3	2	4	6	2	1	1	1	6
2000	1	1	2	3	2	3	5	2	1	1	6
2001	18	16	18	18	24	16	24	39	13	9	50
2002	36	145	108	60	61	80	53	82	132	44	196
2003	5	7	23	8	5	5	6	4	6	10	19
2004	9	9	11	19	7	4	4	5	3	5	24
2005	24	12	11	7	11	4	2	2	3	2	16
Median	282	1,041	1,801	1,372	1,073	540	423	261	132	94	372
Average	1,770	3,217	5,250	5,074	9,526	4,403	3,616	4,205	5,187	1,765	3,774

Table 1b.14. Estimated Bogoslof region pollock Model 4 age 5+ begin-year biomass (with CV), female spawning biomass, age-5 recruitment (numbers), and full-selection fishing mortality rates, for 1977-2005.

Year	Age 5+	CV	Spawning biomass	Age 5 Rec.	Full selection F
1977	1,051,600	19%	479,955	210,509	0.017
1978	1,104,100	19%	499,024	348,264	0.014
1979	1,461,600	19%	642,938	818,896	0.022
1980	1,864,400	18%	814,880	957,611	0.014
1981	2,373,000	16%	1,035,842	1,177,060	0.019
1982	2,658,000	15%	1,173,160	925,577	0.010
1983	4,283,900	14%	1,848,167	3,018,030	0.011
1984	4,107,100	13%	1,827,815	565,109	0.010
1985	3,755,500	12%	1,714,629	290,367	0.005
1986	3,424,100	11%	1,580,299	227,352	0.013
1987	3,125,900	10%	1,408,032	353,096	0.181
1988	2,327,600	11%	1,081,217	165,229	0.053
1989	1,977,700	10%	922,662	190,489	0.025
1990	1,688,500	10%	775,168	131,910	0.133
1991	1,299,200	11%	569,573	109,491	0.422
1992	789,630	15%	367,390	105,410	0.000
1993	725,830	14%	335,925	120,519	0.002
1994	780,310	14%	353,819	279,757	0.001
1995	739,960	13%	337,139	134,059	0.001
1996	666,280	13%	306,872	67,778	0.001
1997	614,050	13%	283,631	78,913	0.000
1998	546,060	12%	253,501	46,323	0.000
1999	476,980	12%	223,122	35,328	0.000
2000	427,820	12%	199,910	49,189	0.000
2001	421,330	13%	194,038	104,015	0.001
2002	381,040	13%	175,957	49,570	0.004
2003	355,120	13%	163,741	61,970	0.000
2004	370,550	15%	168,379	114,204	0.000
2005	591,490	20%	257,181	429,508	0.000
2006	627,760	19%			

Table 1b.15. Projections of Model 4 female spawning biomass for Bogoslof pollock for the 7 scenarios.

B100%		B40%		B35%		B2005	
351,100		140,400		122,900		253,900	
Catch	Max. Perm. ABC	Authors Recom.	Half Max. Perm F	Avg. F	No Fishing	Status Determ. 1	Status Determ. 1
2005	100	100	100	100	100	100	100
2006	189,988	100	105,078	424	0	240,548	189,988
2007	172,333	244,086	114,358	560	0	191,845	172,333
2008	130,134	170,219	102,610	600	0	129,820	163,840
2009	108,469	126,344	92,425	616	0	108,229	119,947
2010	99,460	107,006	86,646	636	0	100,946	104,613
2011	94,921	97,963	83,334	663	0	97,298	98,422
2012	92,845	93,918	80,403	670	0	96,216	96,530
2013	92,721	93,088	79,098	673	0	97,277	97,348
2014	94,283	94,405	79,262	683	0	98,798	98,807
2015	93,370	93,374	78,611	687	0	97,823	97,821
2016	92,721	92,743	78,111	688	0	96,939	96,937
2017	90,979	90,988	76,802	685	0	94,825	94,824
2018	90,113	90,115	76,268	684	0	94,241	94,240
Fishing M.	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2006	0.498	0.000	0.249	0.001	0.000	0.676	0.498
2007	0.498	0.498	0.249	0.001	0.000	0.668	0.498
2008	0.474	0.496	0.249	0.001	0.000	0.598	0.638
2009	0.451	0.470	0.246	0.001	0.000	0.566	0.583
2010	0.438	0.449	0.243	0.001	0.000	0.552	0.558
2011	0.431	0.436	0.241	0.001	0.000	0.546	0.548
2012	0.432	0.433	0.240	0.001	0.000	0.547	0.547
2013	0.430	0.431	0.239	0.001	0.000	0.548	0.548
2014	0.431	0.432	0.239	0.001	0.000	0.547	0.547
2015	0.428	0.428	0.238	0.001	0.000	0.544	0.544
2016	0.426	0.426	0.237	0.001	0.000	0.542	0.542
2017	0.425	0.425	0.237	0.001	0.000	0.538	0.538
2018	0.422	0.422	0.236	0.001	0.000	0.536	0.536
Spawning biomass	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2005	253,928	253,928	253,928	253,928	253,928	253,928	253,928
2006	258,950	275,227	266,938	275,203	275,234	253,449	258,950
2007	209,085	274,007	246,568	294,674	294,873	187,674	209,085
2008	177,930	209,969	230,033	314,032	314,419	153,718	174,287
2009	162,394	176,485	216,996	326,685	327,242	141,293	148,406
2010	152,906	158,676	205,810	333,467	334,174	134,373	136,635
2011	148,195	150,399	198,499	338,474	339,307	131,267	131,930
2012	149,448	150,240	197,263	345,067	346,003	133,484	133,658
2013	150,098	150,374	196,141	348,660	349,675	134,533	134,570
2014	151,183	151,270	196,204	351,446	352,520	135,586	135,589
2015	147,979	148,005	192,616	349,836	350,957	132,355	132,353
2016	148,394	148,411	192,644	351,191	352,349	132,795	132,794
2017	145,554	145,560	189,374	348,695	349,881	130,098	130,097
2018	144,521	144,523	187,812	347,263	348,469	129,276	129,276

Table 1b.16. Summary results for Model 4, Bogoslof region pollock. ABC and OFL levels for 2006 and 2007 are shown where was assumed to be the same as in recent years for 2006.

Age	5	6	7	8	9	10	11	12	13	14	15
M	0.255	0.255	0.255	0.255	0.255	0.255	0.255	0.255	0.255	0.255	0.255
Prop. F. Mature	0.421	0.451	0.474	0.482	0.485	0.500	0.500	0.500	0.500	0.500	0.500
Fish. Selectivity	0.196	0.488	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

	Base model	Model 4
	Tier	3
	Age 5+ 2006 begin-year biomass	626,000
	2006 Spawning biomass	253,900
	$B_{40\%}$	140,400
	$B_{35\%}$	122,900
	$B_{40\%}$	351,100
Full Selection F's		
	$F_{40\%}$	**0.498**
	$F_{35\%}$	**0.676**

Year	Catch	ABC	OFL	SSB
2006	100	190,000	240,500	275,200
2007		244,000	306,100	274,000

Figures

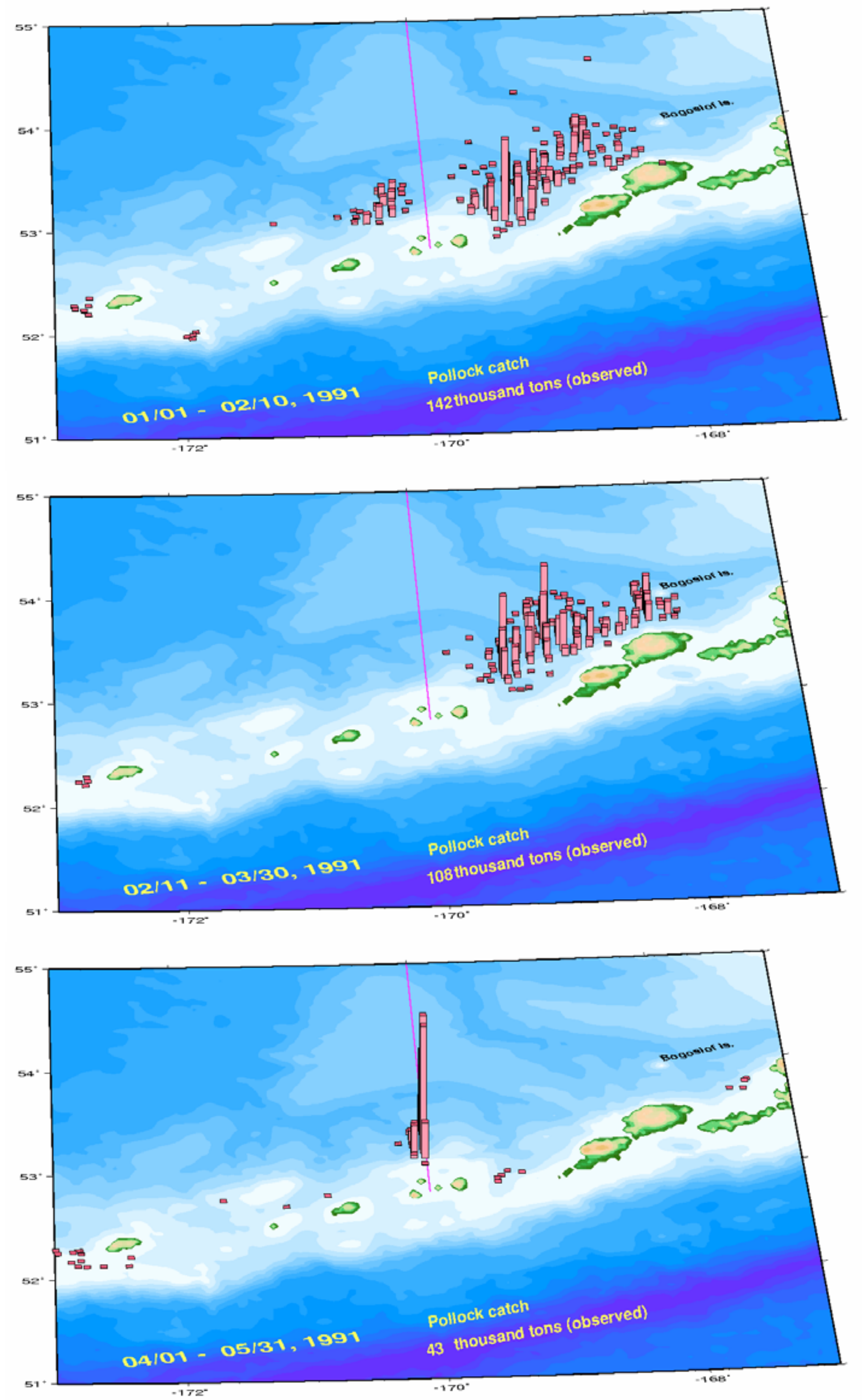


Figure 1b.1. Concentrations of the Bogoslof pollock fishery in **1991** through different periods (Jan 1-Feb 10, Feb 11-Mar 31, Apr 1-May 31, top to bottom).

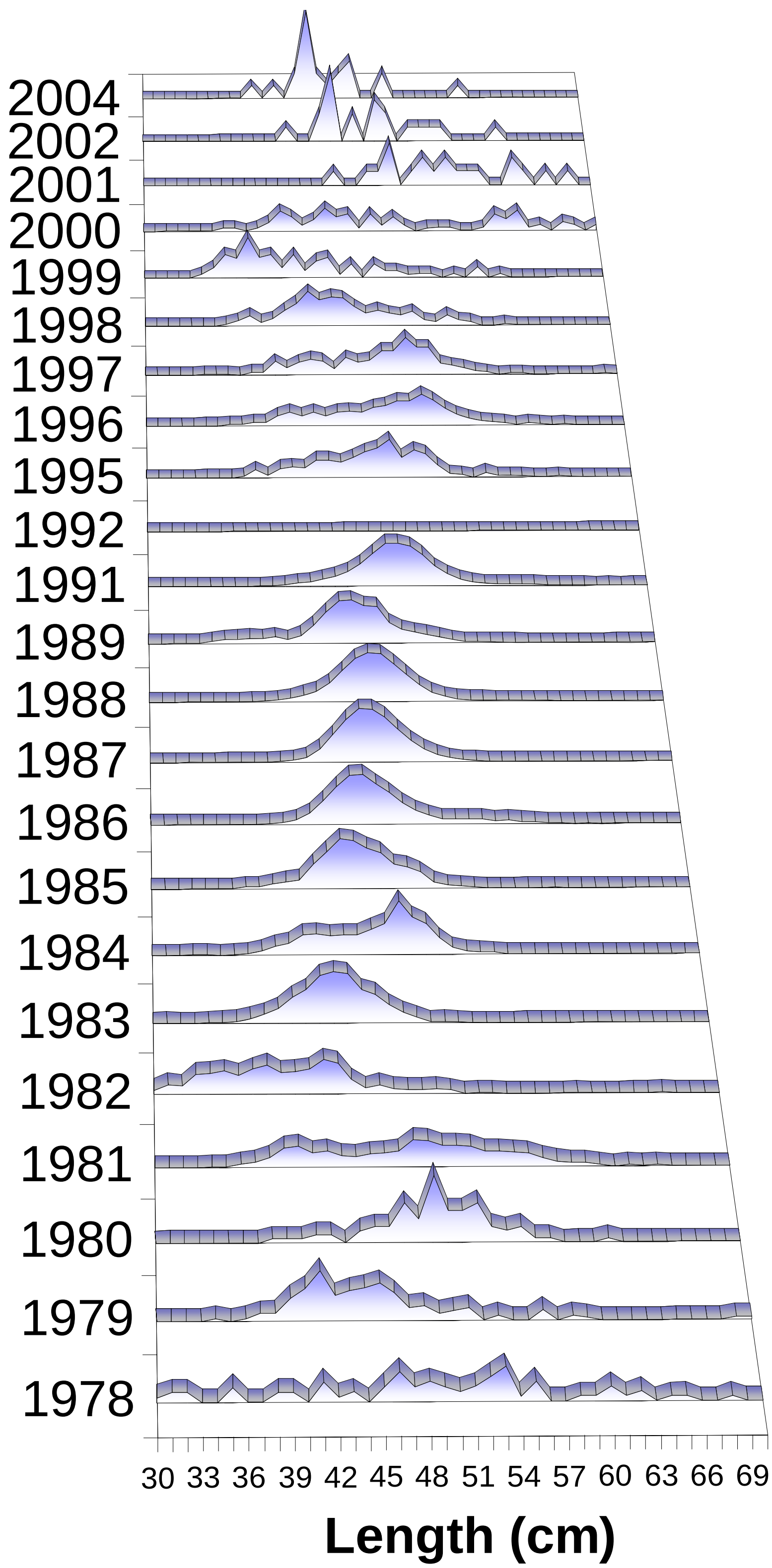


Figure 1b.2. Length frequency proportions of Bogoslof pollock based on observer data from fishery catches for 1978-2004. Note that sample sizes for most years (except 1985-1991) are very small.

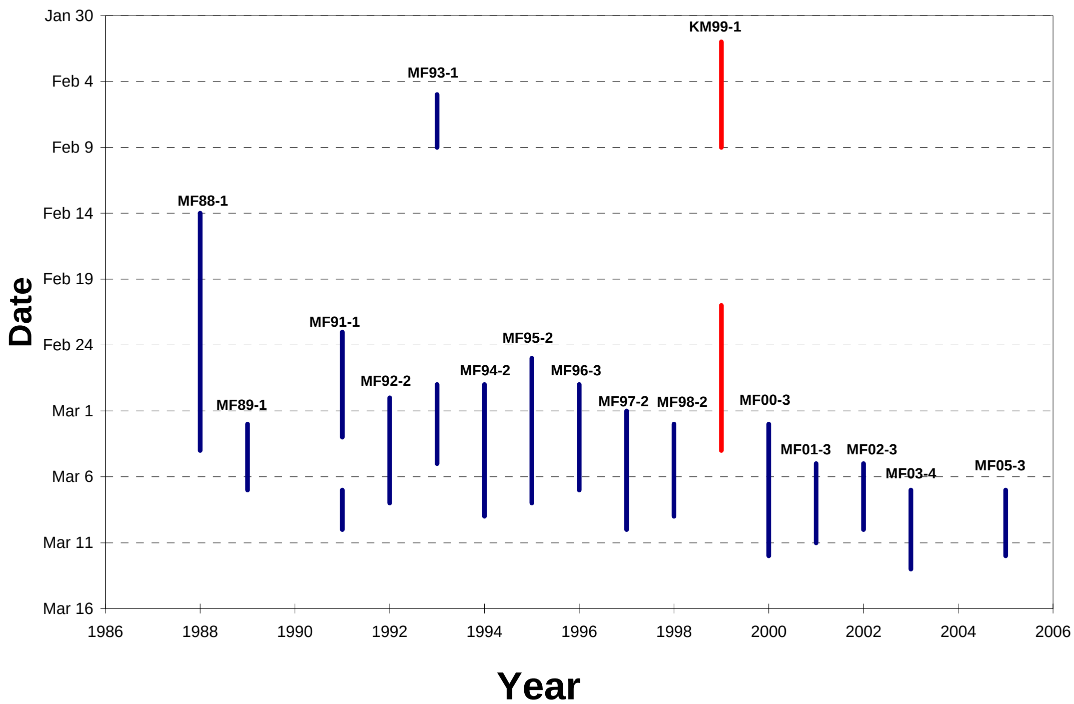


Figure 1b.3. Time periods of Bogoslof EIT surveys as conducted by AFSC (except in 1999 when the survey was conducted from a Japanese research vessel). Cruise names are listed at the beginning of each survey period.

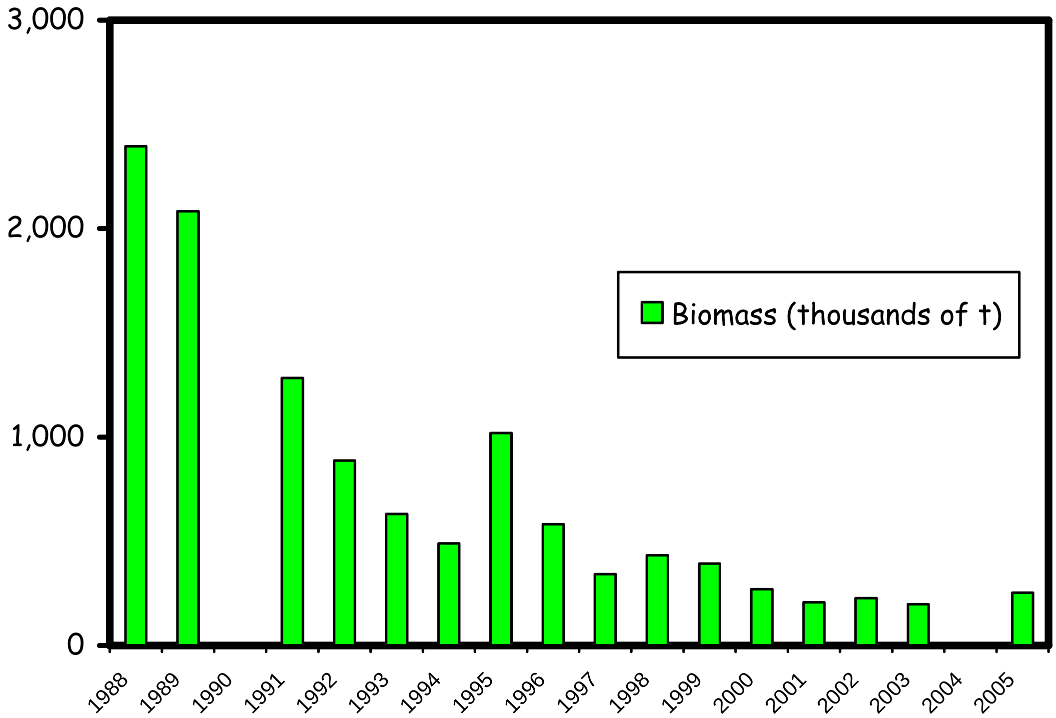


Figure 1b.4. Pollock biomass estimates from the 1988-2005 Bogoslof Area (INPFC area 518) EIT surveys in thousands of tons. There were no surveys in 1990 and in 2004.

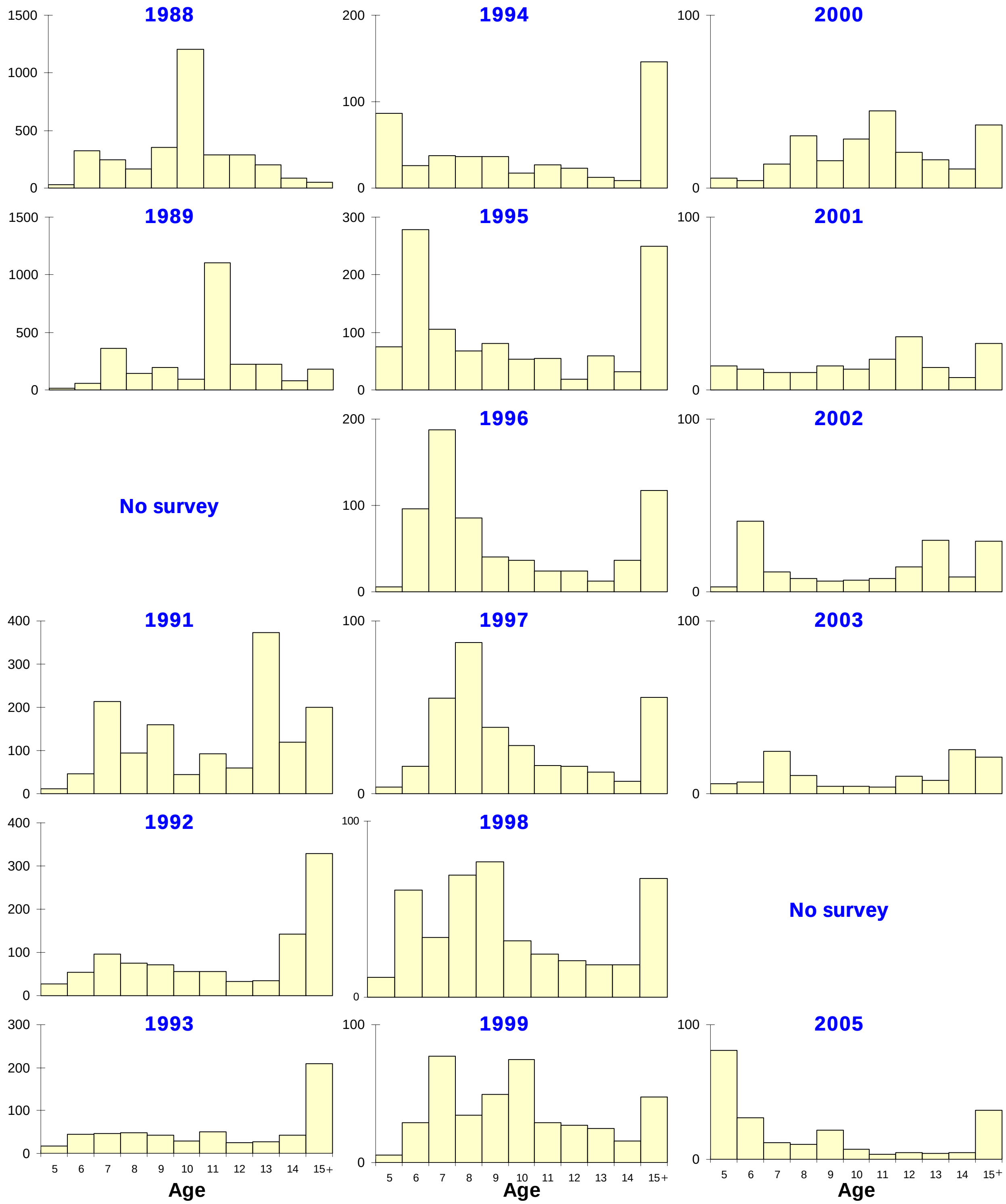


Figure 1b.5. Numbers-at-age estimates (millions) obtained during echo integration-trawl surveys of walleye pollock near Bogoslof Island in winter for ages 5-15+, 1988-2005. The AFSC conducted all but the 1999 survey (done by the Japanese Fisheries Agency). No surveys were conducted in 1990 and 2004. Note that vertical scales differ.

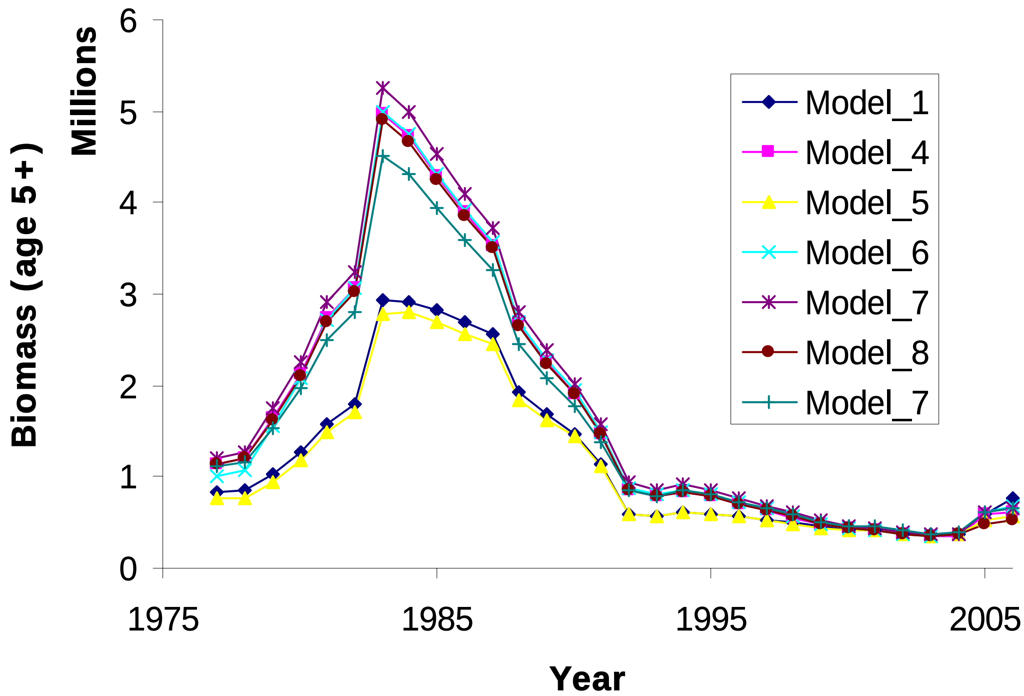


Figure 1b.6. Comparisons of different model specifications on estimates of age 5 and older Bogoslof region pollock biomass (tons). See text for explanation of different model assumptions.

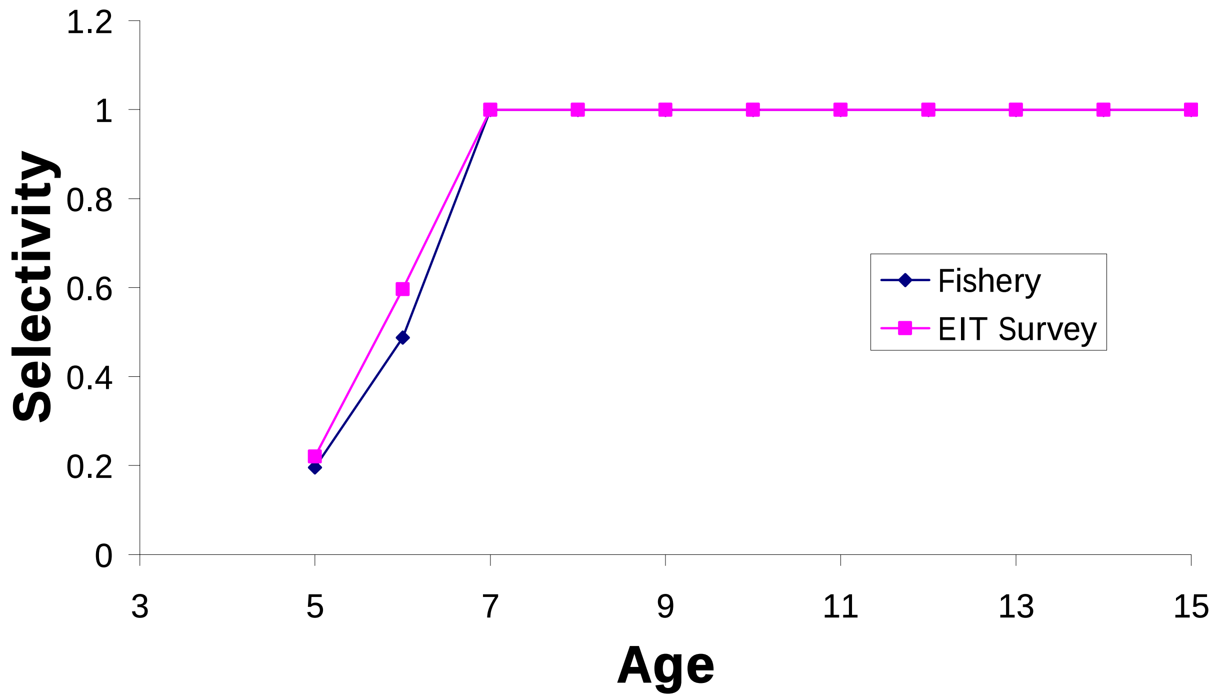


Figure 1b.7. Selectivity patterns estimated (and assumed for ages 7 and older) for the Bogoslof pollock survey and fishery under Model 4.

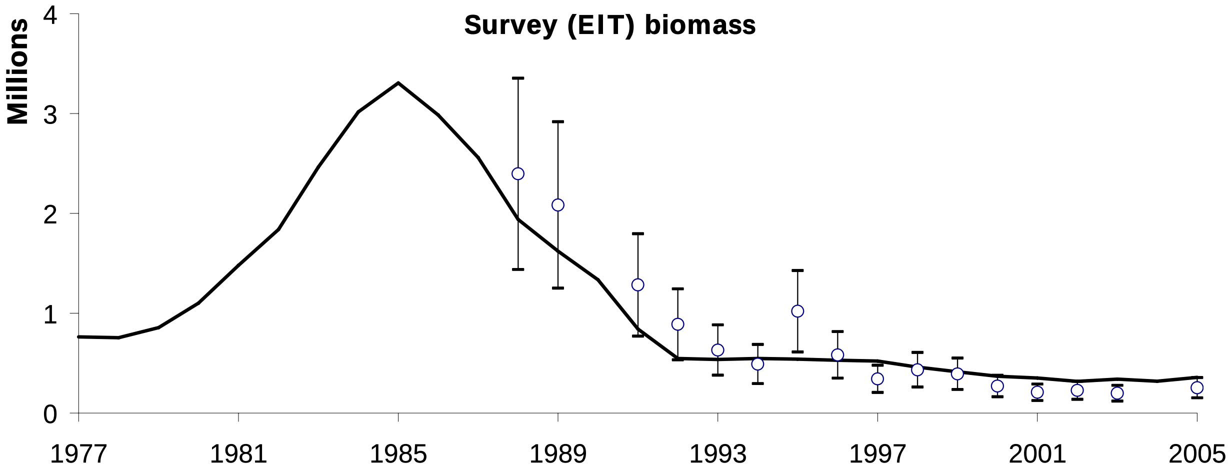


Figure 1b.8. Predicted Model 4 EIT survey biomass (line) versus observed survey estimates (circles) biomass (tons) of Bogoslof region pollock, 1988-2005. Vertical bars represent two times the annual standard deviations assumed for fitting the survey abundance index.

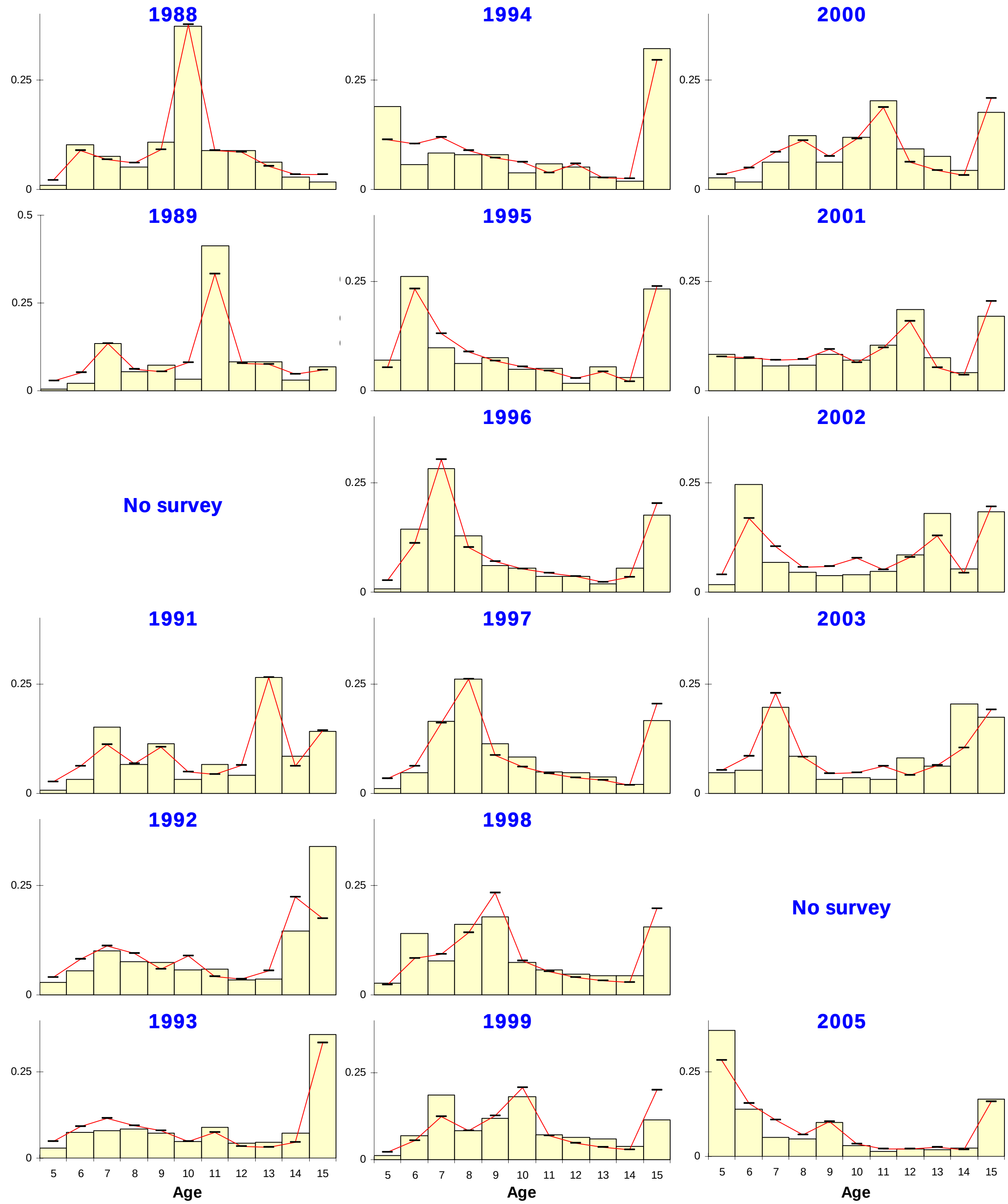


Figure 1b.9. Model 4 estimates (lines) versus observed EIT survey (bars) proportions-at-age of Bogoslof region pollock, 1988-2005.

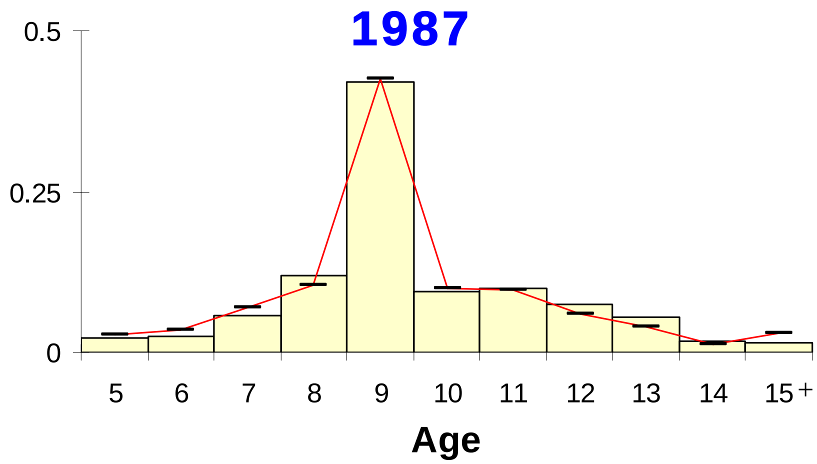


Figure 1b.10. Model 4 estimates (lines) versus observed fishery (bars) proportions-at-age of Bogoslof region pollock, 1987 (the only year where age-data are available).

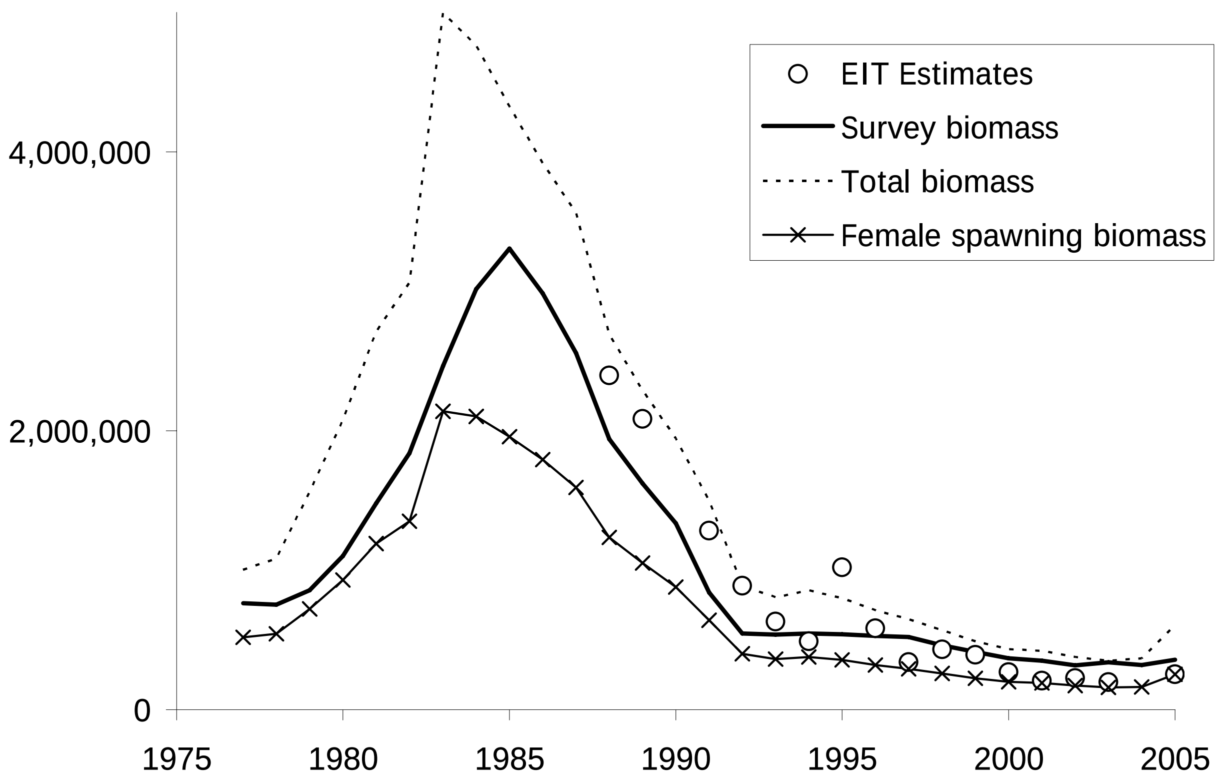


Figure 1b.11. Bogoslof pollock biomass measures as estimated by Model 4, 1977-2005. Units are in tons. The thick line represents the model prediction of the survey biomass. Note that 50:50 sex ratio is assumed for estimates of female spawning biomass.

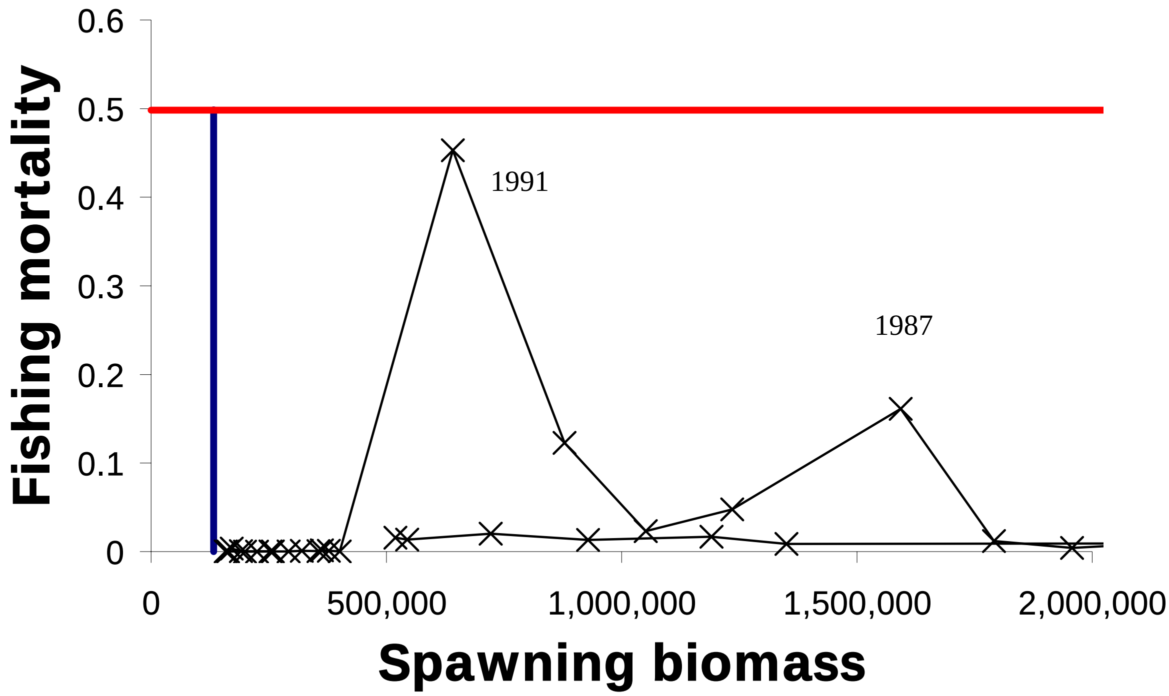


Figure 1b.12. Model 4 spawning biomass relative to fishing mortality rates for Bogoslof pollock, 1977-2005. Fishing mortality rates are based on the average over ages 5-15, horizontal line represents the estimate of $F_{40\%}$ and the vertical line represents $B_{40\%}$.

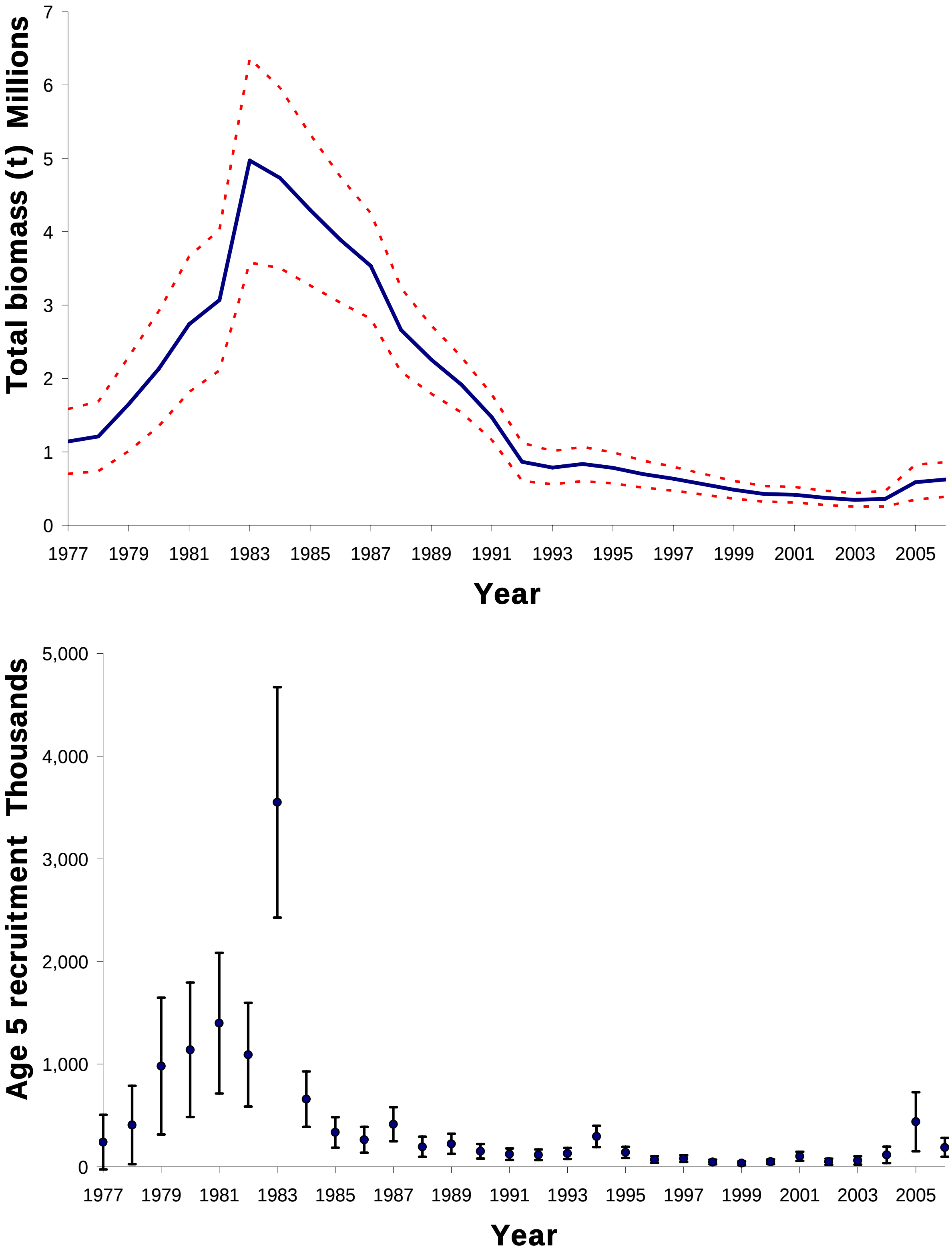


Figure 1b.13. Total age 5+ Model 4 Bogoslof pollock biomass estimated by the model (top panel) and age-5 recruitment (bottom panel) with ± 2 standard deviations of the estimates.

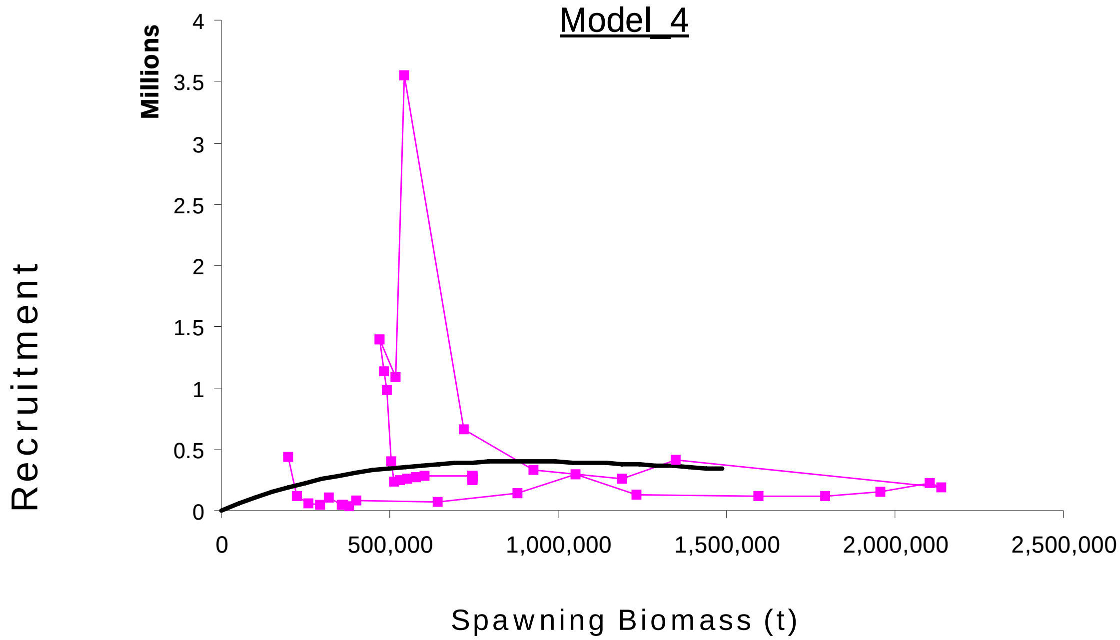


Figure 1b.14. Bogoslof pollock recruitment vs female spawning biomass 1977-2005. The curve represents the estimated stock-recruitment relationship.

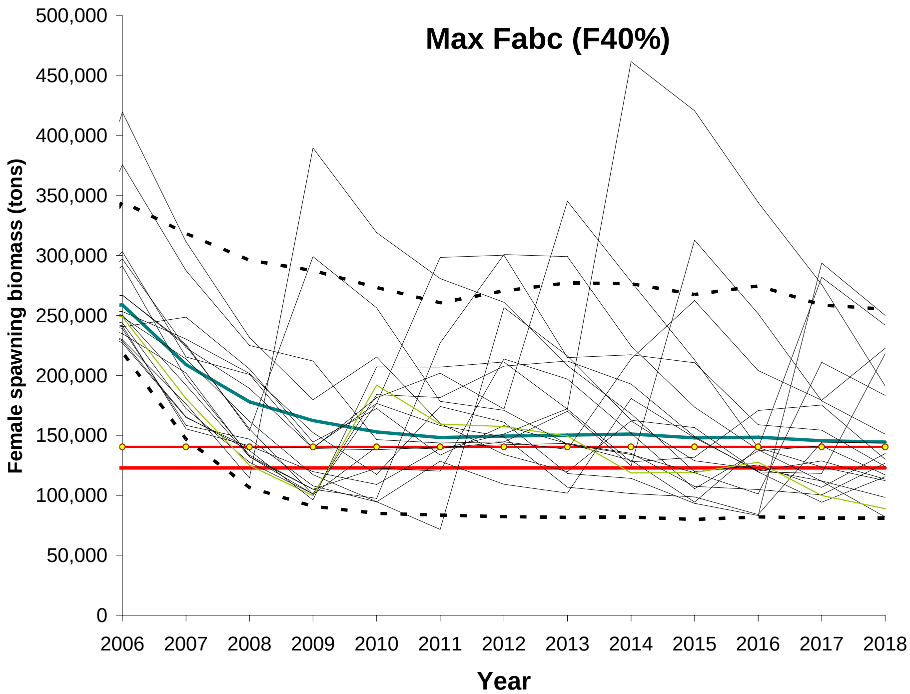
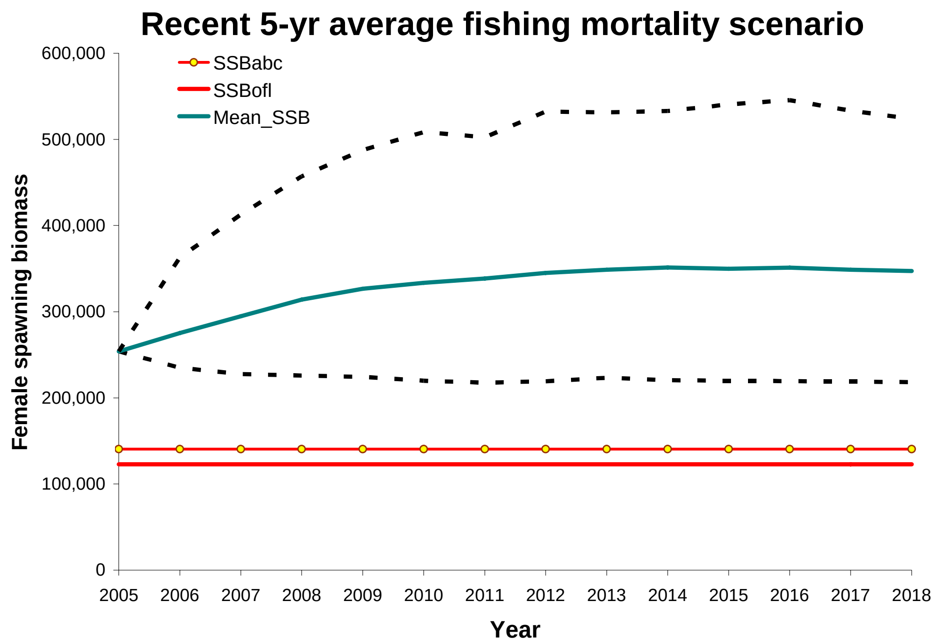


Figure 1b.15. Bogoslof pollock projected female spawning biomass (tons) based on Model 4 under fishing at the maximum-permissible rate. Dotted lines represent 80% confidence bands, lower constant vertical line is the biomass at F_{msy} ($F_{35\%} = F_{OFL}$) and the second low constant value represents $B_{40\%}$. Individual lines are depicted to show the extent of variability expected for any single trajectory.



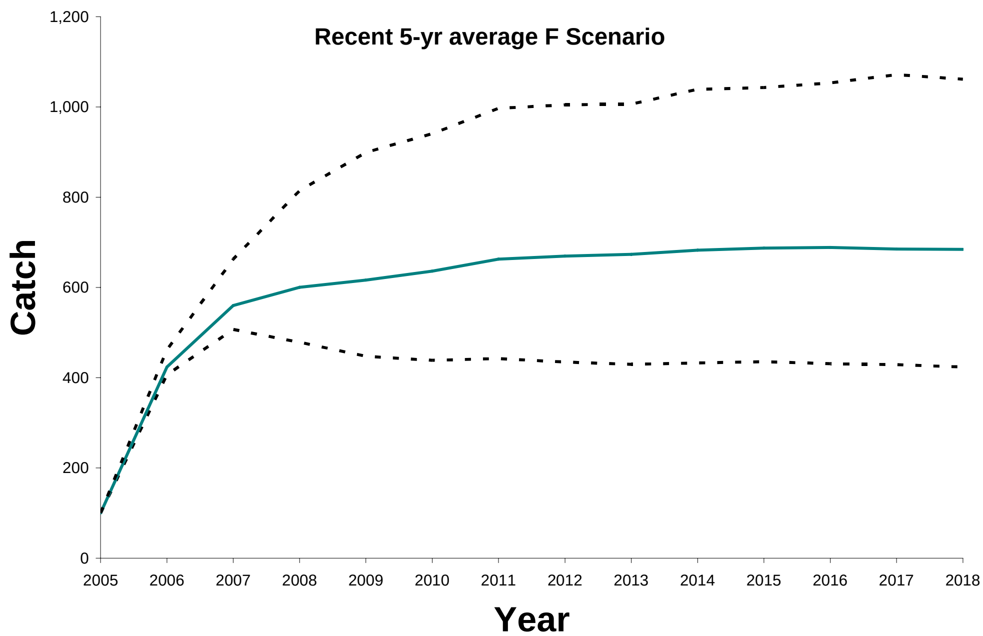


Figure 1b.16. Bogoslof pollock projected female spawning biomass (in t, top panel) and catch (bottom panel) based on Model 4 under the recent 5-year average fishing mortality scenario.

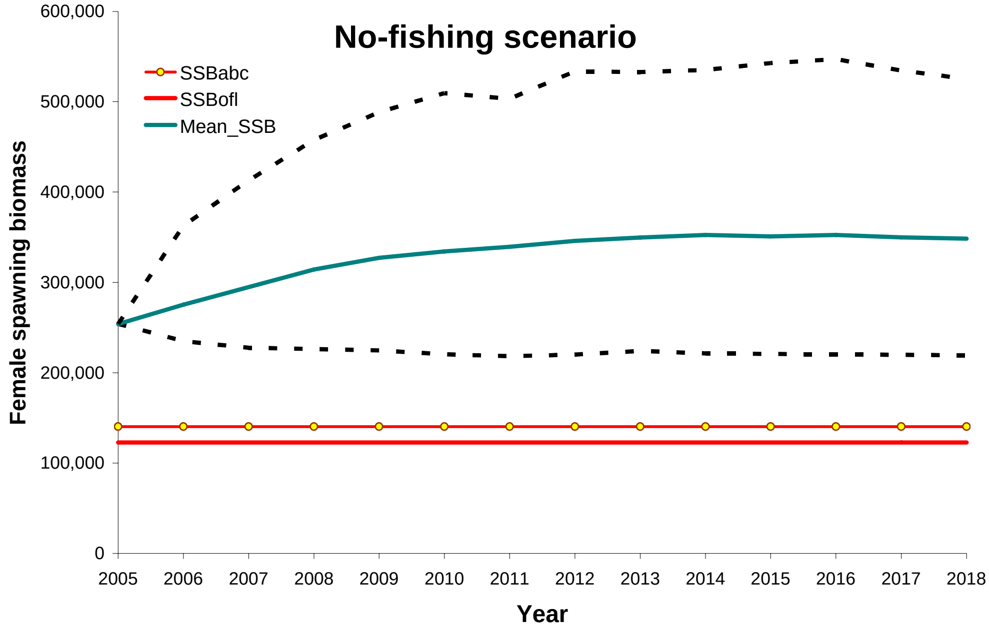


Figure 1b.17. Bogoslof pollock projected female spawning biomass (tons) based on Model 4 under no fishing.

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